

was assumed in a former paper.¹ The case is next considered where the disturbing force is regularly periodic in time; this is the assumption appropriate for the tidal problem. The forces which act on the spheroid in this case do not form a rigorously equilibrating system; but there is a small couple called into existence, the consideration of which is deferred to a future paper.

It appears that the bodily tide lags, and is less in height than it would be if the spheroid were perfectly fluid; also the ocean tides on such a spheroid are accelerated, and are less in height than they would be on a rigid nucleus.²

This theory is then applied to the lunar semi-diurnal and fortnightly tides, and numerical tables of results are given.

A comparison of the numbers given with the viscosity of pitch at near the freezing temperature (as roughly determined by the author) shows how enormously stiff the earth must be to resist the tidally distorting influence of the moon. It may be remarked that pitch at this temperature is hard, apparently solid and brittle; and if the earth was not very far stiffer than pitch, it would comport itself sensibly like a perfect fluid, and there would be no ocean tides at all. It follows, therefore, that no very considerable portion of the interior of the earth can even distantly approach the fluid condition.

This does not, however, seem conclusive against the existence of bodily tides in the earth of the kind here considered; for, under the enormous pressures which must exist in the interior of the earth, even the solidest substances might be induced to flow to some extent like a fluid of great viscosity.

The theory of the bodily tides of an "elastico-viscous" spheroid is next developed. The kind of imperfection of elasticity considered is where the forces requisite to maintain the body in any strained configuration diminish in geometrical progression, as the time increases in arithmetical progression. There are two constants which define the mechanical nature of this sort of solid: first, the coefficient of rigidity, at the instant immediately after the body has been strained; and second, "the modulus of the time of relaxation of rigidity," which is the time in which the force requisite to maintain the body in its strained position has diminished to $\frac{1}{368}$ of its initial value. The author is not aware that there is any experimental justification for the assumption of such a law; but after considering the various physical objections which may be raised to it, he concluded that the investigation was still of some value.

The laws of flow of such an ideal solid have been given (with some assistance from Prof. Maxwell) by Mr. Butcher,³ and they are such that the solutions already found might easily be adapted to the new hypothesis. The results of the application to the tidal problem are not quite so simple as in the case of pure viscosity. By a proper choice of the two constants, the solution becomes either that for a purely viscous spheroid or for a purely elastic one. This hypothesis is therefore intermediate between those of pure viscosity and pure elasticity.

Sir William Thomson worked out numerically the bodily tides of elastic spheres with the rigidities of glass and of iron; and tables of results are given for those rigidities, with various times of relaxation of rigidity, for the semi-diurnal and fortnightly tides.

It appears that if the time of relaxation of rigidity is about one-quarter of the tidal period, then the reduction of ocean-tide does not differ much from what it would be if the spheroid were perfectly elastic. The acceleration of high tide still, however, remains considerable; and a like observation may be made in the case of pure viscosity approaching rigidity. This leads the author to think that perhaps one of the most promising ways of detecting such tides in the earth, would be by the determination of the periods of maximum and minimum in a tide of long period in a high latitude.

The second part of the paper contains a dynamical investiga-

¹ On the Influence of Geological Changes on the Earth's Axis of Rotation. *Phil. Trans.*, vol. clxvii. Pt. I.

² The law is as follows:—If $\frac{v}{2\pi}$ be the frequency of the tide, μ the coefficient of viscosity, g , gravity, a , earth's radius, w , earth's density, and if $\tan \epsilon = \frac{19\mu v}{2gaw}$, the tide of the viscous spheroid is equal in height to the equilibrium tide of a perfectly fluid spheroid multiplied by $\cos \epsilon$, and the tide is retarded by $\frac{\epsilon}{v}$. Also the equilibrium tide of a shallow ocean overlying the nucleus is equal to the like tide on a rigid nucleus multiplied by $\sin \epsilon$, and there is an acceleration of the time of high water equal to $\frac{\pi}{2v} - \frac{\epsilon}{v}$.

³ *Proc. Lond. Math. Soc.*, December 14, 1876, pp. 107-20.

tion of the ocean tides in an equatorial canal running round a yielding nucleus, and the results are confirmatory of the previous ones.

The author states as the chief practical result of this paper that it is strongly confirmatory of the view that the earth has a very great effective rigidity; but that its chief value is, that it forms a necessary first chapter to the investigation of the precession of viscous and imperfectly elastic spheroids—an investigation which he hopes to complete very shortly.

PHYSICAL GEOLOGY¹

A Geological Proof that the Changes of Climate in past times were not due to changes in the position of the Pole; with an attempt to assign a minor limit to the duration of Geological Time.

IF we examine the localities of the fossil remains of the Arctic regions, and consider carefully their relations to the position of the present North Pole, we find that we can demonstrate that the Pole has not sensibly changed its place during geological periods, and that the hypothesis of a shifting pole (even if permitted by mechanical considerations) is inadmissible to account for changes in geological climates.

We are thus driven to the conclusion that geological climates are due to the combined cooling of the earth and sun; and on comparing the rates of cooling of such a body as the earth with the maximum measured thicknesses of the several strata, we find a remarkable proportion between them, which leads towards the conclusion that the maximum thicknesses of the strata are proportional to the times of their formation; and so I deduce a minor limit of geological time.

Climate of the Parry Islands in the Jurassic Period.—Capt. M'Clintock found in the Parry Islands, on the north coast of America, at Point Wilkie, in Prince Patrick's Island, lat. $76^{\circ} 20'$, tropical shells, and drew the attention of geologists to the difficult task of providing a tropical climate inside the Arctic Circle, to accommodate the habits of the animals that lived there in jurassic times. The tropical fossils found in the Parry Islands were:—

Ammonites M'Clintocki (M'Clintock).

Monotis septentrionalis "

Pleurotomaria sp. "

Nucula sp. "

Ichthyosaurus sp. (vertebræ) (Sir Edward Belcher).²

Teleosaurus sp. (vertebræ) (Capt. Sherard Osborne).³

The *Teleosaurus* was a reptile closely resembling the gavial of India, which is found nowhere outside the Tropics, and requires warmer water than the alligator of America. The alligator flourishes in the neighbourhood of New Orleans, whose climate is represented by the following figures:—

Mean Monthly Temperature of New Orleans.

January	54° 8' F.	July	+ 81° 6' F.
February	56° 4' "	August	+ 81° 2' "
March	62° 9' "	September	+ 78° 5' "
April	69° 0' "	October	+ 69° 8' "
May	74° 8' "	November	+ 60° 2' "
June	79° 9' "	December	+ 56° 0' "
Yearly mean	68° 7' F.		

¹ Reptiles requiring a climate such as is indicated by the preceding table, lived in the jurassic period within 900 miles of the North Pole, where the present climate is represented by the following figures:—

Mean Monthly Temperature of Melville Island.

January	- 31° 3' F.	July	+ 42° 4' F.
February	- 32° 4' "	August	+ 32° 6' "
March	- 18° 2' "	September	+ 22° 5' "
April	- 8° 2' "	October	+ 2° 8' "
May	+ 16° 8' "	November	+ 21° 1' "
June	+ 36° 2' "	December	+ 21° 6' "
Yearly mean	+ 1° 2' F.		

¹ "Notes on Physical Geology." Paper read at the Royal Society, April 4, by the Rev. Samuel Houghton, M.D. Dublin, D.C.L. Oxon, F.R.S., Professor of Geology in the University of Dublin. No. IV.

² Exmouth Island, lat. $77^{\circ} 12' N$. (only 900 miles from the Pole).

³ Rendezvous Hill, at north-west extremity of Bathurst Island, lat. $77^{\circ} N$.

Climate of Spitzbergen in the Triassic Period.—The Triassic beds of Spitzbergen, lat. 79°, have afforded species of

<i>Nautilus</i>		<i>Ceratites</i>
<i>Ammonites</i>		<i>Halobia</i>

closely allied to, if not identical with, those of the St. Cassian beds of South Austria.

Climate of Alaska in the Triassic and Jurassic Periods.—In the neighbourhood of Cook's Inlet, in Alaska, lat. 60° N., shells characteristic of the triassic and jurassic periods have been found:—

<i>Monotis</i> ...	Triassic. ¹
<i>Aucella</i> ...	Jurassic.
<i>Ammonites Wosnessarski</i> ...	"
<i>Ammonites biplex</i> ...	"
<i>Belemnites pascillosus</i> ...	"
<i>Pleuromya unioides</i> ...	"

and similar fossils are found along the Pacific Coast of North America.

It is not possible to explain the occurrence of tropical animals in the three above-mentioned localities, by any change in the position of the earth's axis, even if so great an amount of change as would be required were possible. This statement can be proved as follows:—Let a great circle be drawn, joining Spitzbergen with Cook's Inlet, Alaska; this circle will pass nearly through the North Pole. In order to explain the tropical climate of these two localities, and also of the Parry Islands, the pole must be displaced at right angles to the great circle joining Spitzbergen and Alaska, along the meridian long. 117° E., nearly that of Pekin. The present difference of latitude between New Orleans and Spitzbergen is 45°; so that, in order to make the Arctic regions tropical, we must move the North Pole 45° on the meridian of Pekin, bringing it within 300 miles to the north of that city. Hence it follows that, during the triassic period, Pekin lay under the North Pole, covered by the polar ice-cap. Let us now consider what the South Pole was doing: it had moved on the opposite meridian, and had reached the mouth of the Rio Negro, on the east coast of Patagonia, about 1,000 miles to the south-south-east of Valparaiso and the Chilean Andes. Jurassic strata have been found in the Chilean Andes at 34° S., containing the tropical *Ammonites biplex*, which is found also in Alaska, 60° N., and in Europe. This locality lies within 700 miles of the necessary position of the South Pole, and cannot have enjoyed a tropical climate. The proposed alteration of the North Pole is consistent with the occurrence of tropical animals in the Parry Islands, in Spitzbergen, and in Alaska; while the proposed alteration of the South Pole would permit tropical animals to exist in New Zealand and New Caledonia; but the occurrence of jurassic ammonites within 700 miles of the South Pole is fatal to the proposed shifting of the axis of rotation, even if that were allowable to the extent required.

The Climate of the Arctic Regions during the Tertiary Miocene Period.—There is abundant evidence to show that during the miocene tertiary period the northern parts of the continents of America and Europasia possessed a nearly common forest vegetation, with a temperate climate, resembling that now enjoyed by the northern parts of Italy, such as Lombardy.

The localities in which the lignite beds are found, that indicate the former existence of this remarkable vegetation, are the following:—

Greenland (Disco), lat. 70°.
Grinnell Land, lat. 81° 44'.
Spitzbergen (West Coast), lat. 77°.
Alaska and Mackenzie River, lat. 70° to 60°.

The genus *Sequoia* (redwood) has representatives in all these localities, and one Greenland species, *S. gigantea*, is very near the great Californian species which lived in North America in cretaceous times (and still live in California). In Spitzbergen there are found in the miocene beds two species of *Libocedrus*; and of these, one, viz., *L. decurrens*, is now living in California among the Redwoods, while the other still lives in the Andes of Chili. The common *Taxodium* (cypress) of the Southern States occurs fossil in the miocene beds of Spitzbergen, Greenland, and Alaska.²

¹ Triassic slates, containing *Monotis* and *Halobia*, have been recently discovered in places widely separate from each other, all over the globe, viz.:—New Zealand, New Caledonia, North-West America, Upper India beyond the Himalayas, and in Spitzbergen.

² The following genera have been described by Prof. Heer as found at Mackenzie River and Alaska; there are many species of each:—

All the genera mentioned in the note are found in Greenland and Spitzbergen, as well as in Alaska; and, according to Prof. Heer, indicate a mean annual temperature of 48° F. during the miocene period in localities where the mean annual temperature is now as low as zero. During the eocene tertiary period, according to Ettingshausen, there flourished a flora in the Tyrol, which indicates a mean annual temperature between 74° F. and 81° F., the species being largely Australian in character. According to the same author the miocene flora of Vienna was sub-tropical, corresponding to a mean annual temperature between 68° F. and 79° F., and closely resembling that of sub-tropical America. It can be shown by a method similar to that employed for the triassic and jurassic periods, that the North Pole was practically in the same place during the miocene period that it now occupies.

If we join the Mackenzie River and Spitzbergen by the arc of a great circle the North Pole must be moved at right angles to this arc, away from Greenland, through 30°, in order to give all these northern localities a Lombardic climate. The direction in which the pole must be moved is on the meridian of Nagasaki (one of the Japanese Islands), and it reaches a point close to Yakutsk, within 800 miles of the Peninsula of Kamtschatka and the Island of Saghalien, off the Amoor.

Here we meet with a difficulty similar to that offered by the South Pole in the triassic period. The Island of Saghalien and the Peninsula of Kamtschatka contain miocene coal beds, requiring at least a sub-tropical climate, which would be impossible under the supposed circumstances. Also the Islands of Yesso, Nagasaki, and Kiusiu, somewhat farther off, contain similar coal beds.¹

It is very remarkable that, while there exist so many proofs of a warm climate near the North Pole in former geological periods, there is no evidence from fossils of cooler climates having ever existed in the tropics. It was at one time thought that an exception to this statement occurred in the Island of Java, where, it was asserted, a tertiary flora was to be found, indicating rather a temperate than a tropical climate. The full investigations of Göppert, however, have satisfactorily shown that the tertiary flora of Java is of eocene age, and essentially tropical in character, containing numerous specimens of palms, Musas, peppers, laurels, magnolias, and Proteaceae.

From all these facts we are entitled to conclude that, down to so recent a period as the miocene tertiary, climates depended chiefly on the internal heat derived from the cooling earth. As we are precluded from assigning large changes in the position of the poles as a cause for large changes of climate, a very interesting question thus arises as to the sense in which we call the miocene tertiary a recent period. This question may be thus discussed:—We may regard the plants and animals preserved in the fossil state in the Arctic regions as self-registering thermometers, recording for us the mean temperature of those regions at successive epochs, marking so many fixed points on the earth's thermometrical scale. In addition to these we have the present temperature of the Arctic regions directly observed, and two other temperatures determined by physical and physiological conditions: these are the temperature of boiling water, and the temperature at which albumen coagulates. No stratified rocks could have been formed on the earth before the first point

<i>Planera.</i>	<i>Juglans</i> (walnut).
<i>Castanea</i> (chestnut).	<i>Carya</i> (hickory).
<i>Diospyros</i> (ebony tree).	<i>Rhus</i> (sumach).
<i>Dacquinum</i> (bilberry).	<i>Vitis</i> (vine).
<i>Acer</i> (maple).	

All these are indicative of a Lombardic climate, for their living representatives (excepting *Vaccinium* and *Acer*) do not extend into the north temperate region.

¹ Spitzbergen, and the islands of New Siberia, in miocene times, supported a vegetation pointing to like conditions of climate. Further east the coal-fields of Saghalien seem to be likewise of mid-tertiary age, and those of Yesso, I believe, belong to the same epoch. In the Island of Kiusiu miocene rocks are developed to an enormous extent; the volcanic conglomerates, shales, and sandstones of Nagasaki, seem to exceed 5,000 feet in thickness, and the upper portion of this very important series contained, prior to its denudation, one of the richest coal-fields in the world. In the Island of Takosima, where a good section is obtainable, there exist, within a thickness of little more than 300 feet, no less than fourteen beds of coal, varying from 1 to 8 feet thick, and whose united thickness amounts in the aggregate to about 57 feet. Some of them rest on shales containing remains of the old flora, which bears a close resemblance to that of the district at the present day. Unfortunately this rich fossil flora remains as yet undescribed. The fossil flora of Spitzbergen and New Siberia finds its nearest analogue in that of North China and Japan, so that we are compelled to believe in the former extension of a similar flora over the intermediate districts, as well as in the occurrence of very similar conditions of climate.—"The Border Lands of Geology and History" (pp. 28-9). By Thomas W. Kingsmill. Shanghai 1877.

of cooling down was reached, because there was no water to form them; and no life could have existed on the earth until it cooled down to the latter temperature.

Thus we find in the Arctic regions, the following successive temperatures:—

1.—212° F.	...	Boiling water.
2.—122° F.	...	Coagulation of albumen.
3.—68° F.	...	Triassic and jurassic periods. (Climate of Gulf of Mexico.)
4.—48° F.	...	Miocene tertiary period. (Climate of Lombardy.)
5.—32° F.	...	(Climate of Labrador.)
6.—0° F.	...	Present climate.

The interval between the first and second corresponds to the azoic rocks; that between the second and third to the palæozoic rocks; and that between the third and fourth to the neo-zoic rocks. Now, although we do not know the coefficient that fixes the rate of cooling of the hot earth suspended in cold space, we know the law of such cooling, and can compare, by calculation, the proportions of the foregoing intervals of time with each other.

When this calculation is made we obtain:—

Azoic time...	(212°–122°)	...	33°0 per cent.
Palæozoic time ...	(122°–68°)	...	41°0 "
Neo-zoic time ...	(68°–48°)	...	26°0 "
		100°0	"

In my former note, iii. p. 545,¹ I have given a table of the approximate thicknesses of the several strata in Europe. That table was prepared, with the assistance of the late Prof. Phillips, many years ago, and is not as complete as it might be. I therefore sought the assistance of Prof. Edward Hull, Director of the Geological Survey of Ireland, and with his help I have constructed an improved table.

Converting the maximum thicknesses recorded in that table into percentages, and comparing them with the percentages of time found from the theory of a cooling globe, we find—

Scale of Geological Time.

Period.	From Theory of Cooling Globe.	From Maximum Thickness of Strata.
Azoic	33°0 per cent.	34°3 per cent.
Palæozoic	41°0 "	42°5 "
Neo-zoic	26°0 "	23°2 "
Total	100°0 "	100°0 "

The agreement between these figures, derived from entirely independent sources, is remarkable, and tends to justify the principle held by many geologists, that—

The proper relative measure of geological periods is the maximum thickness of the strata formed during those periods.

This is equivalent to supposing the rate of deposition of strata to have been constant during the period contained in the table, which is probable enough on other grounds; for, although the rock-making forces were greater when the heat was greater, it must be remembered that the land surfaces to be denuded were smaller, and that the sea bottoms, on which the *débris* was to be spread, were also greater. The calculation founded on the theory of the cooling globe cannot with safety be carried down to near the point of equilibrium temperature, which is the Fahrenheit zero (for the Arctic regions under consideration); but we may, without risk, extend the calculation from 48° F. to 32° F.; that is, we may estimate the interval of time from the miocene tertiary epoch, when the Parry Islands and Northern Greenland enjoyed a Lombardic climate, to the epoch (probably long past) when those districts suffered a climate like that of Labrador, but better than that they now have.

The result of the calculation, when reduced to the same scale as that used in the table, is 32 per cent., a result, the importance of which will be better seen by the following propositions which flow from it:—

1. *A greater interval of time now separates us from the miocene tertiary epoch than that which was occupied in producing all the*

secondary and tertiary strata, from the triassic to the miocene epoch.

2. *The enormous interval of time that separates us from the miocene epoch affords ample opportunity for the development of the gigantic mammals, which are commonly supposed to have somewhat suddenly made their appearance on all our continents, and to have disappeared as suddenly.*

All the foregoing facts point to the conclusion that the present condition of the earth's surface is profoundly different from its condition in the geological periods when climates depended chiefly on the internal heat of the earth, and not on that of the sun, as at present.

The following table contains estimates of the number of years required by the several rivers to scrape off one foot from their respective rain-basins, and carry the materials to the sea, where it is spread out on the sea bottoms by ocean currents. The figures are obtained by carefully measuring, at frequent intervals, the total discharge of water and the total weight of mud held in suspension. This weight of mud, reconverted into surface rock, must cover the entire rain-basin to a depth of one foot spread uniformly.

Rates of Denudation of Rain-Basins Lowered One Foot.

Ganges	2,358 years.
Mississippi	6,000 "
Hoang Ho	1,464 "
Yangtse Kiang	2,700 "
Rhone	1,528 "
Danube	6,846 "
Po	729 "

Mean 3,090 "

From this table it appears that atmospheric agencies are capable, at present, of lowering the land surfaces at the rate of one foot per 3,000 years; but since the sea bottoms are to the land surfaces in the proportion of 145 to 52, the rate at which (under present circumstances) the sea bottoms are silted up, that is to say, the present rate of formation of strata, is one foot in 8,616 years. If we admit (which I am by no means willing to do) that the manufacture of strata in geological times proceeded at ten times this rate, or at the rate of one foot for every 861°6 years, we have for the whole duration of geological time, down to the miocene tertiary epoch,

$$861\cdot6 \times 177,200 = 152,675,000 \text{ years.}^1$$

To this must be added at least one-third, as before shown, to bring in the period from the Miocene Tertiary to the time when the Parry Islands and North Greenland had the climate of Labrador.

This gives for the whole duration of geological time a *minimum* of two hundred millions of years.

ACTION OF DRUGS ON THE LIVER²

PROF. RUTHERFORD'S paper described the concluding results of the long research undertaken by him on "The Biliary Secretion with Reference to the Actions of Cholagogues." He pointed out the difficulties which had rendered it impossible for physicians to arrive at precise knowledge as to the actions of substances on the liver from observations on the human subject, and the imperative necessity for having recourse to experiments on animals, whereby some of the factors that complicate the case in the uninjured system may be eliminated, and definite knowledge regarding the action of agents on one of the most important organs of the body instituted for the vague guesses of twenty centuries. Several previous investigators had striven by experiments on animals to settle this question, but all had failed owing to the faulty character of the methods employed. By a new and precise method of continuous collection of the bile, and measurement of the amount secreted every fifteen minutes—with a careful elimination of disturbing factors—the whole physiological pharmacology of the liver has been worked out by Prof. Rutherford—as far as it seems at present desirable to proceed. The actions of as many as forty-six substances on the bile-forming function of the liver have been investigated, and results of much importance for rational therapeutics obtained. Some of the

¹ The coefficient 177,200 is the total number of feet of maximum thickness of all the known stratified rocks.

² Abstract of paper read at the Royal Society of Edinburgh on June 17, by Prof. Wm. Rutherford, F.R.S., Prof. Sir Wyville Thomson (in the absence of Sir Wm. Thomson) in the chair.